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DEVELOPMENT OF A STABLE-BETA TITANIUM ALLOY

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D. B. Hunter

TITANIUM METALS CORPORATION OF AMERICA

233 BROADWAY

NEW YORK 7, NEW YORK

Tenth Quarter Report

October 1 to December 31, 1964

Contract DA-30-069-ORD-3743
New York Procurement District

Army Material Command Management Structure Code 5010.11.8430051
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ABSTRACT

Evaluation of ageable beta alloys Ti-17V-2Fe-2Co-3Al, Ti-17V-7.5Co-3Al and Ti-8Mo-8V-5Co-3Al continued with room and elevated temperature smooth and notched tensile tests, creep stability, oxidation and stress-corrosion tests. Ti-17V-7.5Co-3Al aged more rapidly than Ti-8Mo-8V-5Co-3Al; after aging for 8 hours at 900F, Ti-17V-7.5Co-3Al had a yield strength of 198,000 psi, whereas that of Ti-8Mo-8V-5Co-3Al was only 158,000 psi. In smooth and notched tensile tests at 600F, Ti-17V-7.5Co-3Al displayed more strength than Ti-8Mo-8V-5Co-3Al because of its faster aging response in a given time. However, in creep stability tests and oxidation tests, Ti-8Mo-8V-5Co-3Al was the better alloy. Stress corrosion tests performed upon all five ageable beta alloys developed in this project showed that, in the annealed condition, Ti-8Mo-8V-2Fe-3Al was the most resistant to stress corrosion and Ti-17V-7.5Co-3Al and Ti-8Mo-8V-5Co-3Al the most susceptible. Keywords: Titanium Alloys; Vanadium; Cobalt; Aluminum; Molybdenum; Iron; ...

INTRODUCTION

The original object of this contract was to develop stable-beta titanium alloys capable of being hardened to useful combinations of strength and ductility. However, work has indicated that while hardening could be achieved by addition of sparingly soluble elements, such as Si, the high solution temperatures necessary to dissolve the compound present in such alloys produced a large grain size and low ductility. At the end of the first year's effort, the scope of the contract was expanded to include two other types of alloy: a non-hardening stable-beta alloy and a conventional metastable beta alloy hardening by alpha precipitation. However, work during the second year showed that the two stable-beta alloys selected for further investigation could not be welded, and they were replaced by two "stabilized" alloys, Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al.

This report details certain Phase III tests by which the candidate alloys for Phase IV were evaluated. These included room temperature and 600F smooth and notched tensile tests, hardness, creep, oxidation and stress-corrosion tests.

MATERIALS AND PROCEDURES

Procedures used for tensile, hardness, creep, oxidation and stress-corrosion testing are identical to those described in previous reports.[1-9]

RESULTS AND DISCUSSION

Age Hardening Response of Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al

To determine the aging response of Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al, samples were solution treated for 10 minutes at 1500F, quenched, then aged at 800-950F for up to 24 hours. Vickers hardness readings were taken on the samples; results are given in Tables I and II.

These show that at all aging temperatures employed, Ti-17V-7.5Co-3Al had the faster aging response, with almost a 100-point hardness increase after 8 hours at 900F. For a similar aging time Ti-8Mo-8V-5Co-3Al had only a slight hardness increase.

Room Temperature Tensile Tests

To determine the relative room temperature mechanical properties of Ti-8Mo-5Co-3Al and Ti-17V-7.5Co-3Al, samples of each alloy were prepared for testing in various conditions of heat treatment. A uniform solution treatment of 1500F for 10 minutes was employed, terminated by water quenching. Samples were then aged at temperatures of 800-1000F for times up to 24 hours. Results are given in Tables III and IV, and plots of UTS against aging time for all aging temperatures are shown in Figures 1 and 2.

These tables and figures show that Ti-17V-7.5Co-3Al had the faster aging response at all aging temperatures employed. After aging for 8 hours at 900F, this alloy had an ultimate tensile strength of over 200,000 psi with a yield strength of 197,000 psi. Given the same aging treatment, Ti-8Mo-8V-5Co-3Al had an ultimate tensile strength of only 160,000 psi with a yield strength of 158,000 psi. This difference in aging response may be attributed to the greater beta stabilizing power of Mo in Ti-8Mo-8V-5Co-3Al. However, neither of these alloys confirmed previous indications of combining high strength with good ductility.[8] With yield strengths of 200,000 psi or more, uniform elongation was 0-3%, and total elongations ranged from 1-4%. Ti-17V-7.5Co-3Al seemed especially prone to breakage outside the gage length. Inspection of broken specimens eliminated variation of sheet thickness as a prime cause of this behavior. Microexamination was not helpful in providing an explanation.

To enable strength estimates to be made from hardness measurements on these alloys, statistical correlations between Vickers hardness values and ultimate tensile strengths were determined. Vickers hardness readings were obtained on 36 broken tensile samples of each alloy; to insure accuracy, only tensile samples showing a yield stress and ultimate tensile strength were used in the correlation. For the purpose of the statistical calculations, Vickers hardness was plotted as the independent variable, and ultimate tensile strength as the dependent variable, and a linear regression line assumed and plotted for each set of results. The method of calculation is given by Brownlee.[10] For Ti-8Mo-8V-5Co-3Al the relationship between Vickers hardness and ultimate tensile strength was expressed by the following equation:

$$\text{UTS, psi} = (\text{Vickers Hardness} \times 600) - 50{,}000,$$

and for Ti-17V-7.5Co-3Al:

$$\text{UTS, psi} = (\text{Vickers Hardness} \times 585) - 51{,}500.$$

The slopes of these plots are practically identical, Figures 3 and 4, and similar to the slopes previously obtained on other alloys.[8,9]

Confidence limits of 95% were also plotted on Figures 3 and 4; the degree of scatter was somewhat less with Ti-8Mo-8V-5Co-3Al.

<u>600F Tensile Properties of Ti-17V-2Fe-2Co-3Al, Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al</u>

To determine the elevated temperature properties of these three alloys, samples were tensile tested at 600F after solution treatment at 1500F and aging for 8 or 24 hours at 900F. Results are listed in Table V, and a comparison of the room temperature yield strengths and 600F yield strengths is given in Table VI. This shows the percentage of room temperature yield strength retained at 600F. Two other ageable beta alloys previously reported, Ti-17V-4Fe-3Al and Ti-8Mo-8V-2Fe-3Al are included for comparison.

Table VI indicates that the alloy retaining most strength at 600F was Ti-17V-7.5Co-3Al, and the least, Ti-8Mo-8V-5Co-3Al. Percentages of strength retained varied from 73-88%, depending upon the alloy and heat treatment condition.

Creep Stability Tests

Following the 600F tensile tests of Ti-17V-2Fe-2Co-3Al, Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al, samples of these alloys were subjected to creep tests. Specimens were solution treated for 10 minutes at 1500F, quenched, then aged for either 8 or 24 hours at 900F. Exposure times of 150 hours at temperatures of 600F were used; loads of 90% of the yield stress at 600F were employed. Results are listed in Table VII.

These show that in both aged conditions Ti-8Mo-8V-5Co-3Al had the least amount of deformation, and Ti-17V-2Fe-2Co-3Al the most. Subsequent room temperature tensile tests indicated that both Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al tended to break in the head, outside the gage length. Metallographic examination revealed that cracks existed around similar areas of intact tensile samples.

Room Temperature and 600F Notch Tensile Tests

Notch tensile tests at room temperature and 600F were performed on Ti-17V-2Fe-2Co-3Al, Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al using samples having a notch configuration of K_t=8 as shown in Figure 5. Samples were solution treated for 10 minutes at 1500F, then aged for both 8 and 24 hours at 900F. Results are detailed in Table VIII.

In room temperature tensile tests, both Ti-17V-2Fe-2Co-3Al and Ti-8Mo-8V-5Co-3Al had higher values after aging for 24 hours, whereas Ti-17V-7.5Co-3Al showed a decline in notch tensile strengths after 24 hours aging. However, Ti-8Mo-8V-5Co-3Al had inferior notch tensile strengths, by comparison with the two other alloys, in both aged conditions.

Notch tensile tests at 600F indicated that there was little difference between Ti-17V-2Fe-2Co-3Al and Ti-8Mo-8V-5Co-3Al, whereas Ti-17V-7.5Co-3Al displayed somewhat lower strengths in both conditions of aging.

Room temperature ratios of notch tensile strength to ultimate tensile strength were relatively low, being between 0.48 - 0.6; at 600F the ratios were higher, being between 0.74 - 1.10.

Oxidation Tests on Ageable Beta Alloys

To determine their relative resistance to oxidation, samples of Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al were subjected to exposure for 2 hours at 1500F. Details of the method used are the same as those previously described.[9] Results are given in Table IX. These indicate that Ti-8Mo-8V-5Co-3Al had the lower weight gain of the two alloys, with an average increase of only 0.0041 gms/sq.cm. of surface area after 2 hours at 1500F. As this result is comparable to that of Ti-8Mo-8V-2Fe-3Al, previously obtained, it appears that the presence of Mo in the alloy reduces the weight gain. To what extent, if any, MoO_3 is volatilized and lost during these tests is not known.

Stress-Corrosion Tests

Stress -corrosion tests were carried out upon five ageable beta alloys, developed in this project, in the solution treated condition. Samples were solution treated for 10 minutes at 1500F and then air cooled, and stressed by bending them to a 2T radius. Samples were then coated with salt and exposed for 2 hours at 800F in the manner previously described.[9] For comparison purposes, the commercial ageable beta alloy Ti-13V-11Cr-3Al was included in these tests. All salt-coated samples broke upon reverse bending until flat. As the 2T bend may have been too severe, fresh tests as above were performed using samples bent to a 6T radius. This time, control samples were employed in the unexposed state, and also exposed for the same length of time without a salt coating. Results, given in Table X, indicate that under these conditions the best alloy was Ti-8Mo-8V-2Fe-3Al, with Ti-17V-4Fe-3Al a close second. The two alloys most susceptible to stress corrosion under these conditions appeared to be Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al.

CONCLUSIONS

1. Hardness and room temperature tensile tests showed that Ti-17V-7.5Co-3Al had a faster aging response than did

Ti-8Mo-8V-5Co-3Al. After aging for 8 hours at 900F, the ultimate and yield strengths of Ti-17V-7.5Co-3Al were 206,000 and 197,000 psi respectively, whereas those of Ti-8Mo-8V-5Co-3Al were only 160,000 and 158,000 psi respectively.

2. Tensile tests at 600F on Ti-17V-2Fe-2Co-3Al, Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al indicated that, because of its faster aging response, the latter alloy had the higher tensile strength, especially after the 8 hour age at 900F.

3. Creep stability tests of 150 hours on the same three alloys indicated that Ti-8Mo-8V-5Co-3Al had the lowest amount of deformation. Subsequent room temperature tensile tests suggested that both Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al became notch sensitive.

4. Room temperature notch tensile tests on the above three alloys showed that Ti-8Mo-8V-5Co-3Al had the lowest notch tensile strengths after aging for either 8 or 24 hours at 900F; NTS/UTS ratios were low. In 600F notch tensile tests, Ti-17V-7.5Co-3Al had the lowest strengths in both conditions of aging.

5. Oxidation tests on Ti-17V-7.5Co-3Al and Ti-8Mo-8V-5Co-3Al indicated that the latter alloy had the lowest weight gain after exposure.

6. Stress-corrosion tests performed on the five ageable beta alloys under consideration suggested that, in the annealed condition and under the test conditions, Ti-8Mo-8V-2Fe-3Al was most resistant to stress corrosion and Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al were the most susceptible.

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TABLE I

AGE HARDENING RESPONSE FOR Ti-17V-7.5Co-3Al

Ingot No.	Alloy	Solution Treatment	Aging Time, Hours	Vickers Hardness at Given Aging Temperature, °F: 0	800	850	900	950
V-2920	Ti-17V-7.5Co-3Al	1500F(10min)WQ	0	340				
"	"	"	1		340	344	353	362
"	"	"	2		343	353	383	396
"	"	"	4		351	412	416	405
"	"	"	8		417	426	433	433
"	"	"	16		459	449	452	446
"	"	"	24		411	464	455	429

TABLE II

AGE HARDENING RESPONSE FOR Ti-8Mo-8V-5Co-3Al

Ingot No.	Alloy	Solution Treatment	Aging Time, Hours	Vickers Hardness at Given Aging Temperature, °F: 0	800	850	900	950
V-2900	Ti-8Mo-8V-5Co-3Al	1500F(10min)WQ	0	344				
"	"	"	1		346	335	329	331
"	"	"	2		334	335	330	328
"	"	"	4		337	337	336	332
"	"	"	8		343	351	353	357
"	"	"	16		374	388	391	371
"	"	"	24		373	404	401	426

TABLE III

TENSILE PROPERTIES OF Ti-8Mo-8V-5Co-3Al, INGOT NO. V-2900

Heat Treatment	UTS Ksi	YS Ksi	% Elongation Local	Uniform	in 2 inches	Modulus $x 10^{-6}$
1500F(10min)WQ	134	132	60	15.0	23	12.2
"	136	134	60	16.25	22 5	12.0
1500F(10min)WQ+800F(1hr)AC	152	150	60	2.5	13.5	13.8
" "	148	147	65	2.5	17	13.2
1500F(10min)WQ+800F(8hrs)AC	141	139	50	11.25	18.5	12.8
" "	139	136	50	11.25	18	12.4
1500F(10min)WQ+800F(16hrs)AC	168	161	5	1.25	2	13.8 (1)
" "	165	153	30	3.75	9	12.9
1500F(10min)WQ+800F(24hrs)AC	187	172	20	1.25	6.5	13.8
" "	183	176	30	1.25	6	13.9
1500F(10min)WQ+850F(1hr)AC	144	144	50	0	8	12.8
" "	151	151	45	3.75	11.5	13.5
1500F(10min)WQ+850F(4hrs)AC	151	150	30	7.5	13.5	13.5(1)
" "	155	154	50	6.25	13.0	13.9
1500F(10min)WQ+850F(16hrs)AC	184	175	20	6.25	8.5	14.0
" "	185	176	15	3.75	8	13.9
1500F(10min)WQ+850F(24hrs)AC	226	218	5	0	1	15.3(2)
" "	---	---	--	----	----	14.7(2)
1500F(10min)WQ+900F(1hr)AC	145	144	50	1.25	12.5	13.4
1500F(10min)WQ+900F(4hrs)AC	149	148	40	11.25	19	12.9
" "	149	147	50	10.0	20	13.0
1500F(10min)WQ+900F(8hrs)AC	161	160	25	1.25	9.5	13.1

(1) Sample broke outside gage length.
(2) Sample broke in head test finished in file grips.

TABLE III (continued)

Heat Treatment	UTS Ksi	YS Ksi	% Elongation Local	% Elongation Uniform	% Elongation in 2 inches	Modulus x 10^{-6}
1500F(10min)WQ+900F(8hrs)AC	160	156	15	7.5	11.0	13.7
1500F(10min)WQ+900F(12hrs)AC	176	166	20	5.0	7	13.7
" "	172	167	10	1.25	4	13.8
1500F(10min)WQ+900F(16hrs)AC	192	180	10	1.25	3	14.7
" "	178	172	10	0	3	14.0
1500F(10min)WQ+900F(24hrs)AC	216	203	10	1.25	2.5	15.6(2)
" "	---	---	--	----	----	15.3(1)
1500F(10min)WQ+950F(1hr)AC	147	146	45	0	3.5	13.4
" "	147	146	40	0	7	13.4
1500F(10min)WQ+950F(2hrs)AC	147	146	30	5.0	9.5	13.3
" "	153	151	45	15.0	21.5	13.4
1500F(10min)WQ+950F(4hrs)AC	155	153	30	8.75	15.5	13.8
" "	156	155	5	6.25	7.5	13.7
1500F(10min)WQ+950F(8hrs)AC	179	169	--	----	----	14.6(1)
" "	175	172	10	1.25	4	14.3
1500F(10min)WQ+950F(16hrs)AC	201	189	20	5.0	9.5	15.5
" "	186	175	15	2.5	6	14.4(1)
1500F(10min)WQ+950F(24hrs)AC	205	192	5	0	1	15.7
" "	---	---	--	----	----	15.3(1)
1500F(10min)WQ+1000F(1hr)AC	153	151	30	11.25	16	13.9
" "	147	147	20	0	6	13.6(1)
1500F(10min)WQ+1000F(2hrs)AC	153	151	25	3.75	12	13.8
" "	153	150	20	2.5	7.5	13.8
1500F(10min)WQ+1000F(4hrs)AC	157	154	20	3.75	8.5	14.0
" "	154	146	25	11.25	16	13.4
1500F(10min)WQ+1000F(8hrs)AC	179	167	20	7.5	9.5	14.5
" "	181	170	35	7.5	13	14.9
1500F(10min)WQ+1000F(12hrs)AC	187	179	30	1.25	6.5	15.3(1)
" "	185	175	30	5.0	11	15.1
1500F(10min)WQ+1000F(16hrs)AC	198	---	--	----	----	16.3(1)
" "	197	189	25	0	5	14.9(2)

(1) Sample broke outside gage length.
(2) Sample broke in head, test finished in file grips.

TABLE IV

TENSILE PROPERTIES OF Ti-17V-7.5Co-3Al, INGOT NO. V-2920

Heat Treatment	UTS Ksi	YS Ksi	% Elongation Local	% Elongation Uniform	% Elongation in 2 inches	Modulus x 10^{-6}
1500F(10min)WQ	149	147	30	1.25	5.5	12.7(1)
"	151	148	55	13.75	23	13.0
1500F(10min)WQ+800F(1hr)AC	154	153	5	0	1.5	13.3(1,2)
" "	153	151	20	1.25	3	13.2(1)
1500F(10min)WQ+800F(8hrs)AC	192	179	10	1.25	3.5	13.8(2)
" "	193	182	10	1.25	3.5	13.9(1)
1500F(10min)WQ+800F(16hrs)AC	214	211	--	----	----	15.1(1,3)
" "	224	214	5	1.25	3	15.0(2,3)
1500F(10min)WQ+800F(24hrs)AC	227	223	5	0	0.5	15.3(1,3)
" "	222	218	5	0	0.5	15.1(1)(3)
1500F(10min)WQ+850F(1hr)AC	152	149	50	13.75	20	13.2
" "	152	148	40	5.0	10	13.5(1)
1500F(10min)WQ+850F(4hrs)AC	174	172	10	0	2.5	13.9(1,2)
" "	172	168	10	0	2	13.9(1)
1500F(10min)WQ+850F(8hrs)AC	184	181	20	0	2.5	14.2(1)
" "	187	180	20	0	3.5	14.5(1)
1500F(10min)WQ+850F(16hrs)AC	207	201	5	0	0.5	14.9(2)
" "	206	200	20	0	3	12.3(1,2)
1500F(10min)WQ+850F(24hrs)AC	229	217	10	1.25	3	15.2(1)
" "	220	215	--	----	----	14.7(1,2)
1500F(10min)WQ+900F(1hr)AC	152	148	20	7.5	14.5	13.4
" "	155	153	20	0	6	13.3(1)
1500F(10min)WQ+900F(2hrs)AC	176	172	20	0	4	14.2(1)
" "	177	171	20	0	5	13.7(1)
1500F(10min)WQ+900F(4hrs)AC	189	180	5	1.25	2.5	14.1
" "	193	183	5	1.25	3.5	14.6(1)
1500F(10min)WQ+900F(6hrs)AC	193	186	20	1.25	1.5	14.6
" "	198	187	10	2.5	6	14.2(1)
1500F(10min)WQ+900F(8hrs)AC	210	199	5	1.25	2.5	14.9(2)
" "	202	197	5	0	1	14.5(1,2)

(1) Sample broke outside gage length.
(2) Sample broke in head, test finished in file grips.
(3) Five other samples given the same heat treatment, broke before reaching yield stress.

TABLE IV (continued)

Heat Treatment	UTS Ksi	YS Ksi	% Elongation Local	% Elongation Uniform	% Elongation in 2 inches	Modulus x 10^{-6}
1500F(10min)WQ+900F(16hrs)AC	213	203	5	1.25	2	14.9
" "	227	216	10	0	3	15.3 (2)
1500F(10min)WQ+900F(24hrs)AC	220	207	10	3.75	4.5	15.4 (1,2)
" "	218	207	5	1.25	3	15.2 (2)
1500F(10min)WQ+950F(1hr)AC	149	146	20	1.25	8.5	13.3
" "	147	142	20	10.0	11.5	13.2 (2)
1500F(10min)WQ+950F(2hrs)AC	167	166	--	----	----	14.0 (2)
" "	168	162	5	1.25	4	14.2
1500F(10min)WQ+950F(4hrs)AC	168	160	20	3.75	8.5	13.9
" "	167	161	5	1.25	1.5	13.7 (1)
1500F(10min)WQ+950F(6hrs)AC	190	181	5	1.25	2	14.6 (2)
" "	170	164	5	0	1.5	14.3
1500F(10min)WQ+950F(8hrs)AC	198	196	5	0	0	14.8 (2)
" "	206	190	20	1.25	5	14.7
1500F(10min)WQ+950F(16hrs)AC	213	198	10	0	3.5	14.9 (2)
" "	212	199	10	1.25	4.5	15.0 (2)
1500F(10min)WQ+950F(24hrs)AC	195	182	15	3.75	8	14.3
" "	197	184	15	3.75	8	15.1
1500F(10min)WQ+1000F(1hr)AC	162	162	5	0	2.5	13.4 (1,2)
" "	157	153	5	0	0.5	13.6 (1)
1500F(10min)WQ+1000F(2hrs)AC	173	167	5	5.0	5	14.1 (2)
" "	167	160	10	0	4	13.9 (1)
1500F(10min)WQ+1000F(4hrs)AC	189	176	10	5	6.5	12.1
" "	183	173	20	1.25	5	14.6 (1)
1500F(10min)WQ+1000F(8hrs)AC	190	179	5	1.25	3	15.1 (2)
" "	189	---	--	----	----	13.8 (1,2)
1500F(10min)WQ+1000F(16hrs)AC	199	190	10	2.5	4	14.9 (2)
" "	---	---	--	----	----	14.5 (1,2)

(1) Sample broke outside gage length.
(2) Sample broke in head test finished in file grips.
(3) Five other samples given the same heat treatment, broke before reaching yield stress.

TABLE V

600F TENSILE PROPERTIES OF AGEABLE BETA ALLOYS

Heat Treatment	UTS Ksi	YS Ksi	% Elongation Local	Uniform	in 1-inch	Modulus $x\ 10^{-6}$
Ti-17V-2Fe-2Co-3Al, Ingot No. V-2858						
1500F(10min)WQ+900F(8hrs)AC	159	131	20	5.0	10	13.9
" "	161	137	20	2.5	6	13.3
" "	155	129	20	2.5	7	12.4
1500F(10min)WQ+900F(24hrs)AC	193	173	10	0	4	----(1)
" "	194	173	5	0	2	16.4
" "	189	---	5	0	2	----(1)
" "	191	168	5	2.5	3	16.0
Ti-8Mo-8V-5Co-3Al, Ingot No. V-2900						
1500F(10min)WQ+900F(8hrs)AC	136	122	35	5.0	13	12.4
" "	144	128	40	5.0	14	13.0
" "	142	126	20	5.0	9	15.0
1500F(10min)WQ+900F(24hrs)AC	185	153	20	2.5	8	16.3
" "	184	160	20	2.5	8	14.2
" "	175	153	40	5.0	14	11.7
Ti-17V-7.5Co-3Al, Ingot No. V-2920						
1500F(10min)WQ+900F(8hrs)AC	186	162	10	2.5	6	13.3
" "	192	172	10	2.5	4	13.7
" "	181	---	10	2.5	4	14.6(1)
" "	188	---	10	2.5	4	13.2(1)
" "	191	168	10	2.5	4	14.2
1500F(10min)WQ+900F(24hrs)AC	197	184	5	0	1	15.3
" "	200	184	5	0	1	14.0
" "	208	184	5	2.5	3	13.9
" "	198	176	10	0	2	17.7

(1) Extensometer slipped.

TABLE VI

PERCENTAGES OF ROOM TEMPERATURE YIELD STRENGTH RETAINED AT 600F, BY ALLOY AND HEAT TREATMENT

Alloy	Heat Treatment	RT Yield Strength psi	600F Yield Strength psi	% of RT Yield Strength Retained at 600F
Ti-17V-2Fe-2Co-3Al	1500F(10min)WQ+900F(8hrs)AC	181,000	132,000	73
"	1500F(10min)WQ+900F(24hrs)AC	203,000	171,000	84
Ti-8Mo-8V-5Co-3Al	1500F(10min)WQ+900F(8hrs)AC	158,000	125,000	79
"	1500F(10min)WQ+900F(24hrs)AC	203,000	155,000	76
Ti-17V-7.5Co-3Al	1500F(10min)WQ+900F(8hrs)AC	198,000	167,000	84
"	1500F(10min)WQ+900F(24hrs)AC	207,000	182,000	88
Ti-17V-4Fe-3Al	1500F(10min)WQ+900F(8hrs)AC	156,000	120,000	77
"	1500F(10min)WQ+900F(24hrs)AC	184,000	156,000	85
Ti-8Mo-8V-2Fe-3Al	1500F(10min)WQ+900F(8hrs)AC	180,000	142,000	79
"	1500F(10min)WQ+900F(24hrs)AC	191,000	154,000	81

TABLE VII

CREEP STABILITY PROPERTIES OF THREE AGEABLE BETA ALLOYS

Heat Treatment	Exposure Temp. °F	Exposure Stress Ksi	Exposure Time Hours	% Def.	UTS Ksi	YS Ksi	Subsequent Tensile Properties % Elongation Local	% Elongation Uniform	% Elongation in 1-inch	Modulus x 10⁻⁶
Ti-17V-2Fe-2Co-3Al, Ingot No. V-2858										
1500F(10min)AC+900F(8hrs)AC	---	---	---	-----	197	180	10	3.75	7(3)	14.9(1)
" "	600	119	150	0.655	199	179	5	2.5	4	----
" "	"	"	"	0.971	200	195	5	0	2	13.4(1)
" "	"	"	"	0.611	202	182	10	0	4	14.3
1500F(10min)AC+900F(24hrs)AC	---	---	---	----	220	204	15	2.5	5(3)	15.1(1)
" "	600	154	150	0.582	213	210	5	0	1	15.3
" "	"	"	"	0.560	215	211	10	5.0	6	15.5
" "	"	"	"	0.665	208	207	10	2.5	6	15.3
Ti-8Mo-8V-5Co-3Al, Ingot No. V-2900										
1500F(10min)AC+900F(8hrs)AC	---	---	---	----	160	156	15	7.5	11(3)	13.7
" "	600	113	150	0.164	156	152	5	2.5	3	13.8(2)
" "	"	"	"	0.167	156	152	5	2.5	3	10.8(2)
" "	"	"	"	0.160	167	161	10	2.5	5	13.8
1500F(10min)AC+900F(24hrs)AC	---	---	---	----	216	203	10	1.25	2.5(3)	15.6(2)
" "	600	140	150	0.171	186	---	--	----	----	15.0(1)
" "	"	"	"	0.182	---	---	--	----	----	14.6(1)
" "	"	"	"	0.200	193	190	5	0	1	11.7(2)
Ti-17V-7.5Co-3Al, Ingot No. V-2920										
1500F(10min)AC+900F(8hrs)AC	---	---	---	----	209	208	5	0	1.5(3)	14.0(2)
" "	600	150	150	0.353	206	199	--	----	----	14.9(1,2)
" "	"	"	"	0.240	203	199	5	0	1	15.6
" "	"	"	"	0.356	---	---	--	----	----	13.8(1,2)
1500F(10min)AC+900F(24hrs)AC	---	---	---	----	218	207	10	3.75	4.5(3)	15.4(1,2)
" "	600	164	150	0.255	220	213	5	2.5	3	15.5
" "	"	"	"	0.516	216	---	--	----	----	15.8(2)
" "	"	"	"	0.382	226	203	5	2.5	3	14.4(2)

(1) Sample broke outside gage length.
(2) Sample broke in head test finished in file grips.
(3) Total elongation in 2-inches.

TABLE VIII (continued)

Ingot No.	Alloy	Heat Treatment	Test Temp. °F	NTS Ksi	Average	Smooth UTS Ksi	Ratio NTS/UTS
V-2858	Ti-17V-2Fe-2Co-3Al	1500F(10min)WQ+900F(8hrs)AC	600	162)			
"	"	" "	"	152)			
"	"	" "	"	149)	161	159	1.02
"	"	" "	"	167)			
"	"	" "	"	174)			
"	"	1500F(10min)WQ+900F(24hrs)AC	"	166)			
"	"	" "	"	161)			
"	"	" "	"	165)	164	193	0.85
"	"	" "	"	169)			
"	"	" "	"	159)			
V-2900	Ti-8Mo-8V-5Co-3Al	1500F(10min)WQ+900F(8hrs)AC	"	158)			
"	"	" "	"	154)	156	142	1.10
"	"	" "	"	156)			
"	"	1500F(10min)WQ+900F(24hrs)AC	"	167)			
"	"	" "	"	169)	167	182	0.92
"	"	" "	"	164)			
V-2920	Ti-17V-7.5Co-3Al	1500F(10min)WQ+900F(8hrs)AC	"	153)			
"	"	" "	"	156)	150	188	0.80
"	"	" "	"	141)			
"	"	1500F(10min)WQ+900F(24hrs)AC	"	146)			
"	"	" "	"	148)	148	200	0.74
"	"	" "	"	149)			

TABLE VIII

ROOM TEMPERATURE AND 600F NOTCH TENSILE PROPERTIES OF THREE AGEABLE BETA ALLOYS

(Notch Configuration K =8)

Ingot No.	Alloy	Heat Treatment	Test Temp. °F	NTS Ksi	Average	Smooth UTS Ksi	Ratio NTS/UTS
V-2858	Ti-17V-2Fe-2Co-3Al	1500F(10min)WQ+900F(8hrs)AC	RT	106)			
"	"	" "	"	119)			
"	"	" "	"	127)	120	200	0.60
"	"	" "	"	121)			
"	"	" "	"	127)			
"	"	1500F(10min)WQ+900F(24hrs)AC	"	127)			
"	"	" "	"	132)			
"	"	" "	"	129)	129.5	219	0.59
"	"	" "	"	134)			
"	"	" "	"	126)			
V-2900	Ti-8Mo-8V-5Co-3Al	1500F(10min)WQ+900F(8hrs)AC	"	87)			
"	"	" "	"	98)			
"	"	" "	"	106)			
"	"	" "	"	78)	87	160	0.54
"	"	" "	"	71)			
"	"	" "	"	83)			
"	"	" "	"	83)			
"	"	" "	"	92)			
"	"	1500F(10min)WQ+900F(24hrs)AC	"	107)			
"	"	" "	"	81)			
"	"	" "	"	95)			
"	"	" "	"	102)	95	198	0.48
"	"	" "	"	100)			
"	"	" "	"	89)			
"	"	" "	"	108)			
"	"	" "	"	81)			
V-2920	Ti-17V-7.5Co-3Al	1500F(10min)WQ+900F(8hrs)AC	"	117)			
"	"	" "	"	117)	115	205	0.56
"	"	" "	"	110)			
"	"	1500F(10min)WQ+900F(24hrs)AC	"	106)			
"	"	" "	"	114)	107	218	0.49
"	"	" "	"	101)			

TABLE IX

OXIDATION TESTS ON Ti-8Mo-8V-5Co-3Al AND Ti-17V-7.5Co-3Al
(All Samples Exposed for 2 Hours at 1500F)

Ingot No.	Alloy	Sample	Weight Sample grams	Weight Sample+ Crucible Unexposed	Weight Sample+ Crucible - After Exposure	Weight Gain, grams	Gain in Grams/sq. cm. of Surface Area
V-2900	Ti-8Mo-8V-5Co-3Al	A	4.3502	35.0244	35.1131	0.0887)	
"	"	B	4.5128	32.1921	32.2680	0.0759)	0.0041 average
"	"	C	4.4929	32.0712	32.1278	0.0566)	
V-2920	Ti-17V-7.5Co-3Al	A	3.6372	27.6895	27.8465	0.1570)	
"	"	B	3.6962	29.0907	29.2646	0.1739)	0.0147 average
"	"	C	3.7646	31.9100	32.1460	0.2360)	

TABLE X

STRESS CORROSION TESTS ON SIX AGEABLE BETA ALLOYS

Ingot No.	Alloy	Bend Radius	Treatment	Result of Reverse Bending Until Flat
V-2858	Ti-17V-2Fe-2Co-3Al	6.2T	None (control)	No cracks
"	"	5.6T	800F(2hrs), No salt	No cracks
"	"	5.6T	800F(2hrs), Salt coat	Small cracks
"	"	5.4T	800F(2hrs), Salt coat	Small cracks
"	"	6.2T	800F(2hrs), Salt coat	Small cracks
V-2859	Ti-17V-4Fe-3Al	6.5T	None (control)	No cracks
"	"	6.5T	800F(2hrs), No salt	No cracks
"	"	6.5T	800F(2hrs), Salt coat	No cracks
"	"	6.5T	800F(2hrs), Salt coat	No cracks
"	"	6.5T	800F(2hrs), Salt coat	Few small cracks
V-2860	Ti-8Mo-8V-2Fe-3Al	6.0T	None (control)	No cracks
"	"	6.0T	800F(2hrs), No salt	No cracks
"	"	5.6T	800F(2hrs), Salt coat	No cracks
"	"	5.7T	800F(2hrs), Salt coat	No cracks
"	"	6.0T	800F(2hrs), Salt coat	No cracks
V-2900	Ti-8Mo-8V-5Co-3Al	5.7T	None (control)	No cracks
"	"	6.0T	800F(2hrs), No salt	No cracks
"	"	5.7T	800F(2hrs), Salt Coat	Sample broke
"	"	5.8T	800F(2hrs), Salt coat	Sample broke
"	"	6.3T	800F(2hrs), Salt coat	Sample broke
V-2920	Ti-17V-7.5Co-3Al	6.2T	None (control)	No cracks
"	"	6.3T	800F(2hrs), No salt	No cracks
"	"	5.7T	800F(2hrs), Salt coat	Sample broke
"	"	5.8T	800F(2hrs), Salt coat	Sample broke
D-3002	Ti-13V-11Cr-3Al	5.8T	None (control)	No cracks
"	"	5.8T	800F(2hrs), No Salt	No cracks
"	"	5.8T	800F(2hrs), Salt coat	Numerous small cracks
"	"	5.8T	800F(2hrs), Salt coat	Numerous small cracks
"	"	5.8T	800F(2hrs), Salt coat	Numerous small cracks

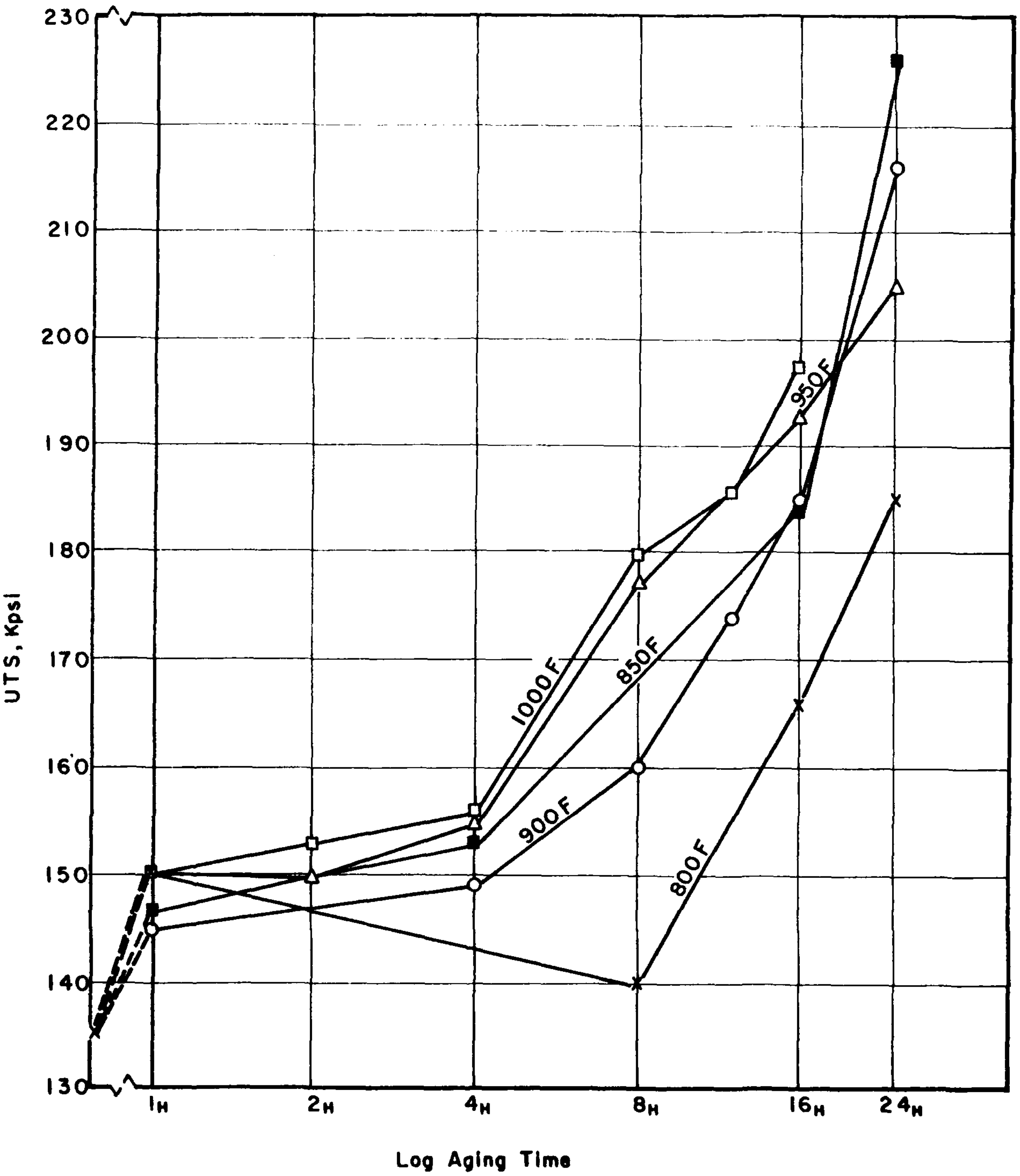


FIGURE I. ULTIMATE TENSILE STRENGTH OF Ti-8Mo-8V-5Co-3Al AFTER AGING AT TEMPERATURE OF 800-1000F. (SOLUTION TREATMENT: 1500F-10 MINUTES W.Q.)

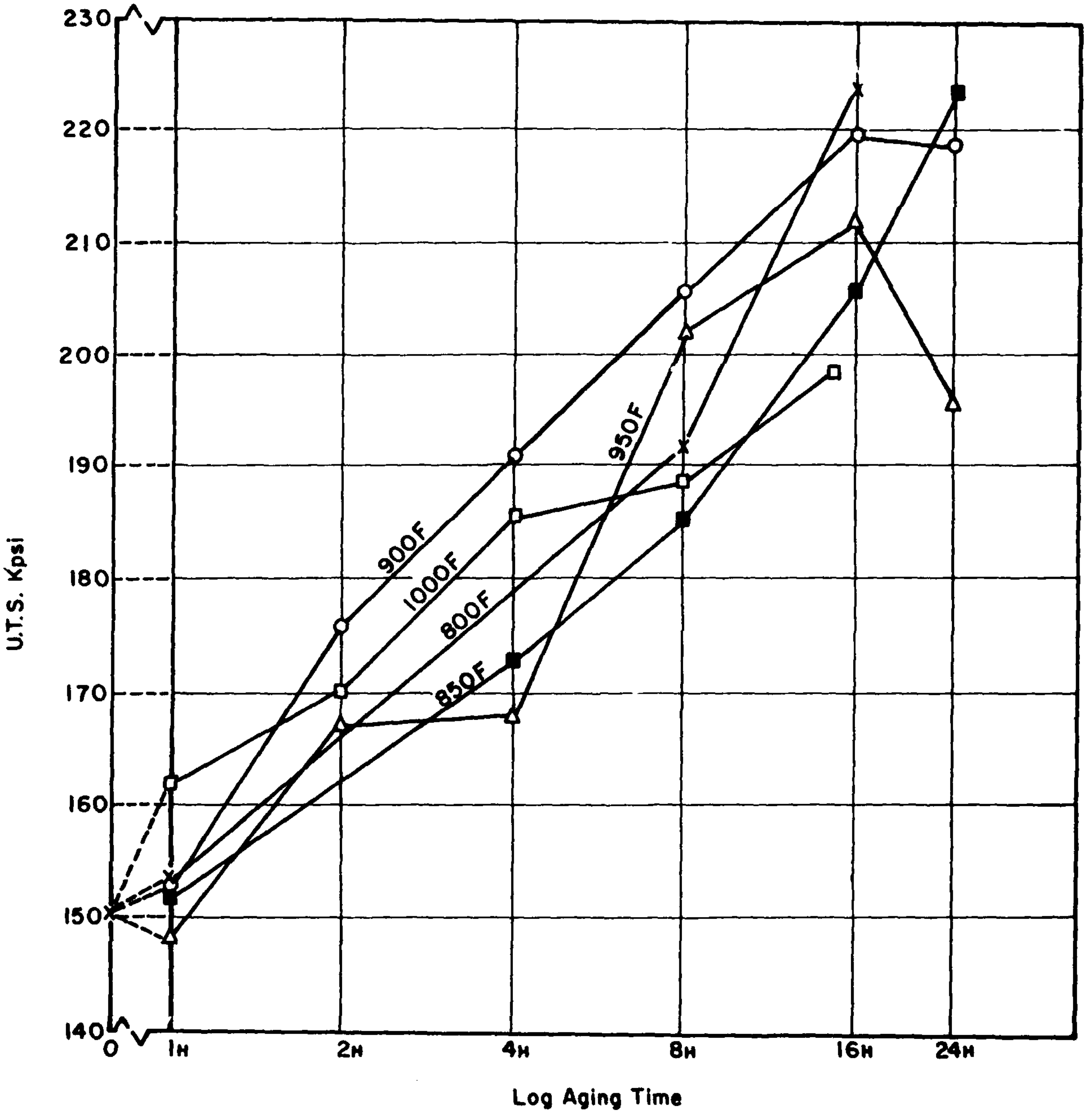


FIGURE 2. ULTIMATE TENSILE STRENGTH OF Ti-17V-7.5Co-3Al AFTER AGING AT TEMPERATURES OF 800-1000F. (SOLUTION TREATMENT: 1500F-10 MINUTES, W.Q.)

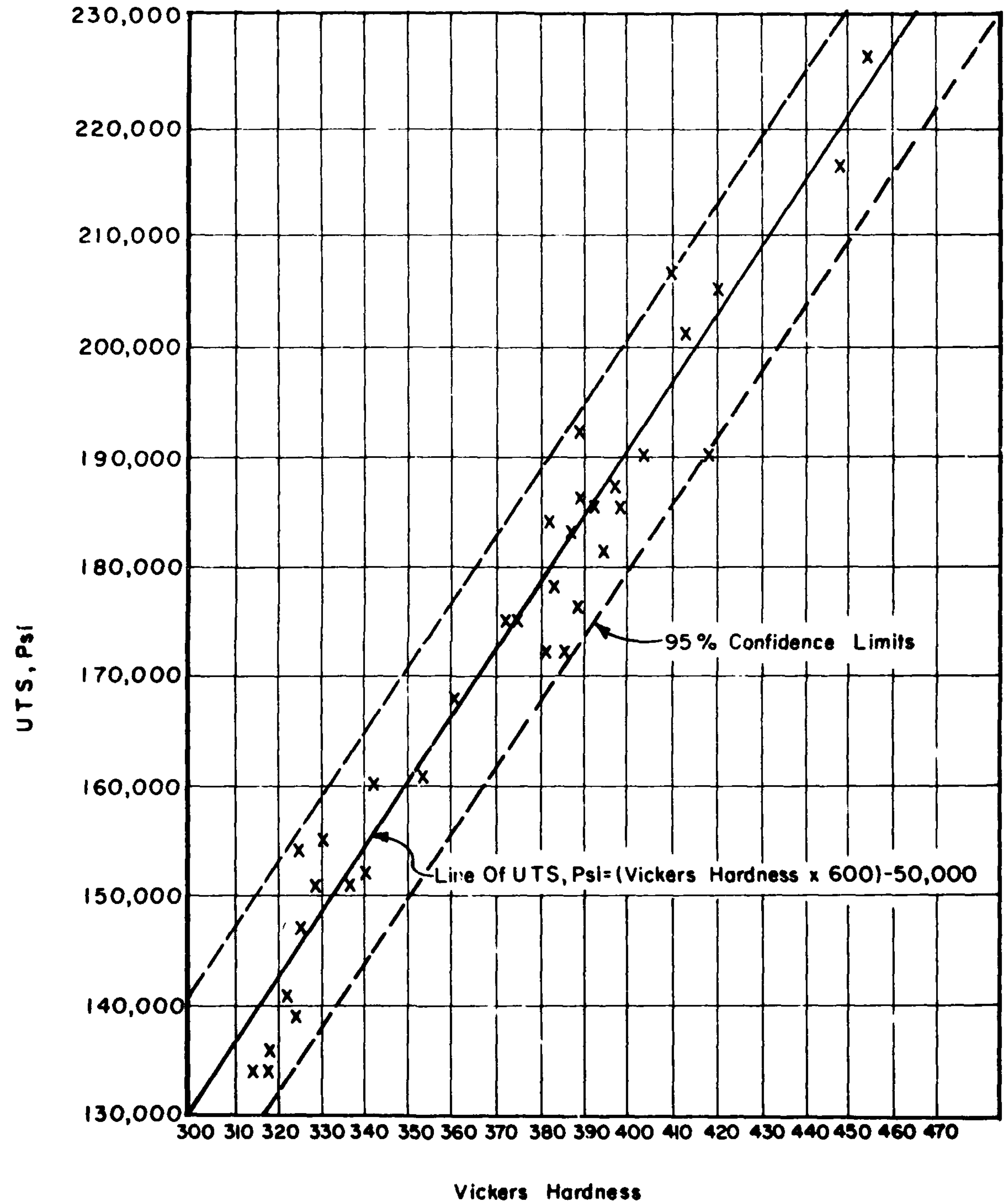


FIGURE 3. STATISTICAL RELATIONSHIP BETWEEN VICKERS HARDNESS AND UTS OF Ti-8Mo-8V-5Co-3Al.

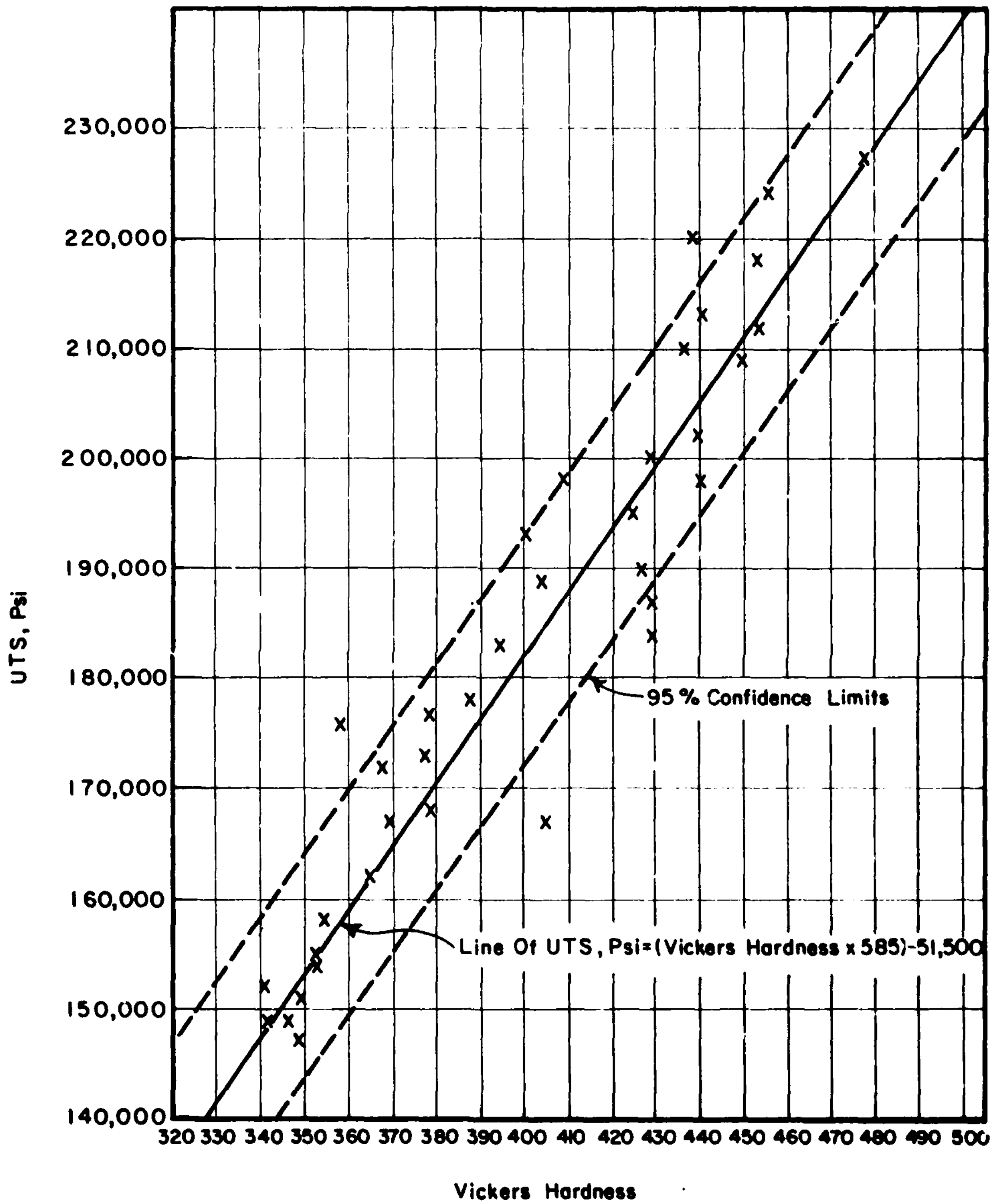
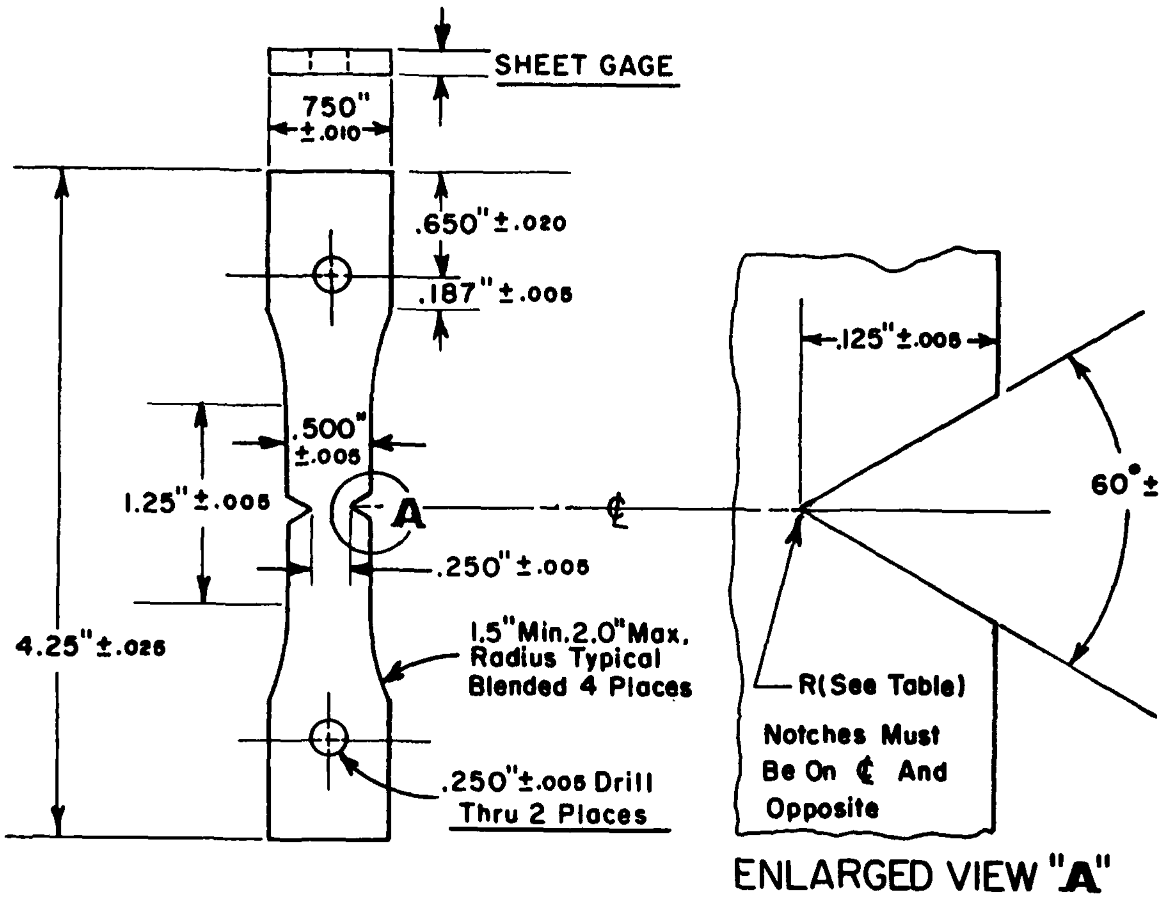


FIGURE 4. STATISTICAL RELATIONSHIP BETWEEN VICKERS HARDNESS AND UTS OF Ti-17V-7.5Co-3Al.



TABLE

R	K_T
$.0025'' {}^{+.0}_{-.0005}$	8.0

FIGURE 5. NOTCHED SHEET TENSILE SPECIMEN.

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